Renewable and Sustainable Energy Reviews 29 (2014) 31–36

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

On energy consumption and GDP studies; A meta-analysis of the last two decades

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ARTICLE INFO

Article history:
Received 10 April 2013
Received in revised form
12 August 2013
Accepted 24 August 2013
Available online 14 September 2013

Keywords:
Energy consumption
GDP growth
Meta-analysis

ABSTRACT

The relationship between energy consumption and GDP growth has been intensely examined in multiple frameworks set by various methods and countries. This paper is a meta-analysis of 51 studies published in the last two decades, with worldwide data since 1949, on the relationship between energy consumption and GDP growth. The aim is to systemize some of the factors that cause the variation of results in these studies. Our results yield evidence that the long run elasticity of GDP growth with respect to energy consumption is not independent of the method employed for cointegration, the data type and the inclusion of variables such as the price level or capital in the cointegration equation. Also 1% increase in capital, increases the elasticity of GDP with respect to energy consumption by 0.85%.

Contents

1. Introduction

A plethora of studies has dealt with the relationship between energy consumption and GDP growth with conflicting results both on the existence and the direction of causality. These are shown in Table 1 of the current paper. Some of the studies already include literature reviews up to the date of their publication. For an example see [1–3]or [4] for a complete literature survey. So far however, no meta-analysis of these studies has been performed. The existent studies are mere narrative reviews with no methodological rigor capable to allow inference, which makes it hard to synthesize this large literature.

A meta-analysis is the statistical analysis of a large collection of disparate research results for the purpose of integrating the findings [5] into a regression equation, or as in [6] the term is described: a "study of studies". Therefore, its aim in the energy consumption-growth nexus is not to make policy recommendations on how energy consumption can be used in an efficient and sustainable way enabling growth at the same time. This is done in the individual studies. A meta-analysis provides a synthesis of the trends in a sample of studies and allows a more detailed overview of them by examining various hypotheses [7].

In [8] it is claimed that one of the greatest strengths of meta-analysis is the ability to combine and summarize large amounts of information from previous studies. Therefore, the meta-analytic sample is a collection of data stemming from the individual studies of the topic of interest. According to [9], meta-analyses rely on shared subjectivity, rather than objectivity, since the authors decide what variables and which studies to include. An extenuation to this comment is the transparency of data collection and the admittance of criticism to other analysts.

The majority of meta-analyses have taken place in psychology, education, medicine, transport and labor economics [10]. Many meta-analytic studies have also taken place in various fields of

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http://dx.doi.org/10.1016/j.rser.2013.08.081

Table 1
Author, publication year and number of observations.

Authors	Year of publication	Observations
Acaravci and Özturk [25]	2010	12
Akinlo [30]	2008	7
Al-Iriani [31]	2006	6
Altinay and Karagol [32]	2004	1
Altinay and Karagol [33]	2005	1
Ang [34]	2007	1
Ang [35]	2008	1
Apergis and Payne [19]	2009a	4
Apergis and Payne [20]	2009b	6
Apergis and Payne [18]	2010	9
Asafu-Adjaye [36]	2000	4
Balcilar et al. [37]	2010	7
Bartleet and Gounder [38]	2010	2
Belloumi [39]	2009	1
Bowden and Payne [40]	2009	5
Chiou-Wei et al. [14]	2008	9
Eggoh, Bangake and Rault [41]	2011	10
Erdal et al. [3]	2008	1
Esso [21]	2010	7
Friedl and Getzner [42]	2003	1
Fuinhas and Marques [43]	2012	5
Ghali and El-Sakka [44]	2004	1
Glasure and Lee [45]	1998	2
Gosh [46]	2002	1
Halicioglu [47]	2009	1
Hamit-Hagar [48]	2012	1
Ho and Siu [49]	2007	1
Hondroyiannis et al. [15]	2002	2
Jalil and Mahmud [50]	2009	1
Lean and Smyth [51]	2010	5
Lee [52]	2005	17
Lee and Chang [53]	2008	16
Lee and Chien [54]	2010	7
Lise and Montford [55]	2007	1
Mahadevan and Asafu-Adjaye [56]	2007	20
Masih and Masih [57]	1996	6
Mozumder and Marathe [58]	2007	1
Narayan and Prasad [27]	2008	30
Odhiambo [59]	2010	3
Odhiambo [60]	2009	1
Oh and Lee [61]	2004	2
Özturk and Acaravci [1]	2010	1
Özturk et al. [2]	2010	3
Paul and Bhattacharya [62]	2004	1
Shiu and Lam [63]	2004	1
Squalli [64]	2007	11
Tsani [65]	2010	4
Wang et al. [66]	2011	1
Yuan et al. [16]	2008	4
Zhang and Cheng [23]	2009	1
Zhixin and Xin [67]	2011	1

Note: One observation means a single country study.

environmental economics but fewer of them have taken place in energy economics; on capital-energy substitution elasticities [11], wind power learning [12] and price elasticity of gasoline [13] are some of the most recent. None to the best of author's knowledge has taken place in the field under study, i.e. the energy consumption and GDP growth nexus.

Studies on the relationship between energy consumption and GDP growth sometimes yield conflicting and ambiguous results due to different methods, sample periods, model specifications being employed [14] or different consumption patterns and presence of omitted variable bias. Besides methodological differences, in [15] more reasons are added for this variety of results: the different institutional, structural frameworks and the policies followed by countries. In [16] the varying impacts from different sources of energy are also reported and the different development stages and processes in each country. [17] also report the cross-section dependence between countries which is usually overseen and this leads to biased results.

Therefore, motivation for this study was the proliferation of studies in the field with their variety of tools and results. It is an intriguing question to answer whether the methods and tools themselves used in the studies are responsible for the results reached. For example whether the cointegration method, the data range, the geographical region the study uses, do indeed play any role in the results of the study. Even the year of publication might be a proxy for the quality of the study, since more sophisticated methods develop through time. Worthy of reporting is that the multiformity of the studies hinders the homogenization of the variables that were extracted from each study, thereby causing a number of missing observations for some variables or an exclusion of some studies from the meta-data set.

The rest of the paper is organized as follows: Section 2 presents basic theory on the relationship between energy consumption and GDP growth, Section 3 is the data description, Section 4 is the model specification, Section 5 comprises the results and their discussion and Section 6 is the conclusion.

2. The relationship between energy and GDP growth

The relationship between GDP growth and energy consumption is important to design an effective energy and environmental policy that will promote sustainable development. Inefficient usage of energy leads in turn to global warming and climate change therefore affecting GDP growth. [18] provides an enlightening account on the relationship between energy and GDP growth and how policy, depending on its aims and objectives, may respond under four major hypothesis. There are four streams of literature [19,20], about this relationship. First, under the growth hypothesis, energy saving policies which reduce energy consumption may have an adverse impact on real GDP, because the economy is very dependent on energy to grow. Energy leads growth and it affects it directly or indirectly as a complement to other input factors of production. The growth hypothesis situation can be met for instance in energy inefficient economies (e.g. with low pollution control technologies or an underdevelopment in renewable energies) or developing countries.

Second, the conservation hypothesis suggests that growth leads energy. Energy consumption can decrease without necessarily a negative effect on growth, therefore in such situations greenhouse reduction measures can be pursued without detriment to growth because causality does not run from energy to growth. Third, the neutrality hypothesis suggests that energy consumption has little or no impact on GDP, therefore, again, a conservative policy will cause no impediment to growth. Hence, in such situation, there is no reason why a conservation policy should not be adopted if necessary. Fourth, the feedback hypothesis suggests that energy consumption and real GDP are interrelated, because there is bi-directional causality and hence they are complements to each other. The policy implications of the feedback hypothesis are the same with the growth hypothesis in that energy conservation measures will eventually decrease growth.

Policy makers need to know the link between energy consumption and GDP growth and which additional variables lead GDP growth in order to manage tools such as rationing energy consumption and controlling carbon dioxide emissions. It is a timely question how to formulate an energy policy focused on a country's social and economic objectives (e.g. supply security, balance of payments) with respect to Kyoto protocol restrictions. Knowledge of the above relationship together with the knowledge of specific economy characteristics and inefficiencies (political constrains, outdated infrastructure, production shifts from energy

intensive to less energy intensive sectors etc.) allows improvement of the energy security of a country. A unidirectional causal relationship from energy consumption to growth reflects an unsustainable energy security situation even with high energy resources present in one country. Most of the studies taken place so far concern developed countries [21].

The methodology applied for the examination of the energy–GDP growth relationship can also be divided by means of the econometric method used. In [22] they are discerned as follows: (i) first generation being the traditional vector autoregression method (VAR) with the assumption of stationarity of the underlying variables, (ii) Eagle and Granger procedure which also accounts for non-stationarity, (iii) Johansen's multivariate approach which accommodates more variables in the cointegration relationship and (iv) panel estimation techniques being the fourth generation.

3. Data description

Typically the energy consumption and GDP growth relationship is studied in an economy production function perspective, including other variables such as capital or labor to avoid bias from omitted variables. Therefore, up-to-date literature can be divided into three strands depending on the focus of research [23]. The first strand focuses on environmental pollutants and GDP growth which end up testing the validity of the Environmental Kuznet's Curve (EKC) hypothesis. The second strand focuses on the relationship of energy consumption and GDP growth beginning with the seminal work by [24] for the U.S.A. with causality running from income to energy, while the third strand is a combined approach of the two aforementioned. Very few studies [25] combine both dimensions. This is also attempted by the current paper from a meta-analytical point of view, and this is reflected in the collected data. The synthesis of the meta-sample is: strand 1 by 3.2%, strand 2 by 88.8% and strand 3 by 8% from the past two decades, contingent upon the studies provision capability of the variables sought. The energy consumption and GDP growth relationship is examined in a production model framework (thereby including variables such as capital or labor) in order to avoid the omitted variable bias [26].

Overall 247 observations were collected from 51 published papers published in the last two decades. They were identified with the keywords “energy consumption and GDP growth” in impact-factored journals related to energy. Papers that bore this topic on their title or keywords but could not yield most of the variables of Table 2 were not included in the sample. The data range is from 1949 to 1995 from all over the world. The largest part of studies (40%) concern the Asian region and almost 25% the European region, followed by 16% in America, 15% in Africa and 4% in Australia. Mean number of observations from each study is 5.21 (st.dev = 6.63), min. value is 1, max. value is 30 and this comes from [27].

Disaggregated multi-country studies yielded one observation for each of the countries they included. Also, aggregated sectoral studies were treated as countries, with every sector counting as a country and thus producing one observation. One of the reasons we had to devote one line for each country or sector is because many studies reported different long-run and causality relationships for the various countries or sectors they encompassed. Besides, the majority of meta-analysis employ multiple observations from each study and not a single one [28,29] Table 1 summarizes the papers from which the observations were compiled, the year of publications and the total number of observations.

Due to the various methods employed for the study of the long-run relationship and causality relationship between energy consumption and GDP growth, and for many studies, this relationship is further enriched with other variables too, there were large differences in the presentation of the findings of the papers and therefore there is a number of missing values (as not applicable) reported for some variables. However, this was a necessary price to pay in order to be able to combine studies with binary and multivariate models.

The generated variables (Table 2) have been grouped into five categories; (i) with general study characteristics, (ii) method of analysis, (iii) countries in the study, (iv) variables included in the long-run relationship and (v) causality direction.

4. Model specification

The dependent variable is long run elasticity of GDP growth with respect to energy consumption, namely the ECEL variable. This is the typical y variable which is a function of a constant a, and a number of explanatory x, variables

$$y_i = X\beta + \varepsilon \tag{1}$$

where i stands for study i, X stands for the variables in Table 2 except for ELEC which is the dependent variable y.

With the typical restrictions of the linear model, namely the three-line equation

$$\begin{aligned} &E[\varepsilon_i/X] = 0, \forall i \\ &\mathrm{Var}[\varepsilon_i/X] = \sigma^2, \forall i \\ &\mathrm{Cov}[\varepsilon_i, \varepsilon_j/X] = 0, \forall i, j \end{aligned} \tag{2}$$

the elasticity of energy GDP with respect to energy consumption is regarded as dependent on a number of X variables related to (i) the data type (TIPA, ELEC, STAB), (ii) the method of cointegration analysis (ARDL, PEDR, JOHA, TODA, COIN), (iii) the number of countries, years in the analysis and start year of the data (NCOU, NYEA, STYEA), (iv) the geographical regions the study concerns (EURO, AMER, AFRI, ASIA), (v) other variables considered in the cointegration equation or causality framework (PRDU, EKCD, CAPI, CO2D, LADB) and (vi) causality results (BIDI). Consistent with this framework, it is attempted to summarize in one equation, both elements of the long-run relationship and the causality situation with other study characteristics that could be classified under the main groups.

A forward stepwise method regression was initially employed to find the variables not yet entered in the model which would raise the squared rho by the largest amount. The correlation matrix of all variables was also estimated but the significant correlations were very low and hence not taken into account. Most of the variables have small variations due to their dichotomous status or small range, i.e. elasticities range between -1 and 1. Therefore, due to the latter the application of a log linear regression was not possible. Moreover, various tests for multicollinearity, heteroskedasticity and heterogeneity have been performed and their results did not reveal any problems.

5. Results and discussion

The software used for the estimations was [68] Limdep, Ver. 9. An OLS model shown in Table 3, was accompanied by tests for heteroskedasticity, heterogeneity and multicollinearity. None of them appeared to be a problem.

Only one of the continuous variables was significant. Significant continuous variables can be interpreted in terms of the percentage increase or decrease of the elasticity of energy consumption. For example the positive significance of CAPI, means that 1% increase in capital, will increase the elasticity of GDP with respect to energy consumption by 0.85%. Since all the rest of significant variables are

Table 2
Description of collected variables.

Variable name	Explanation	Mean	St. deviation
i. General study characteristics			
YEAR	Year of publication*	3.56	4.23
STAB	Stability examined with breaks; 1: yes, 0: no	0.07	0.26
TIPA	Type of data; 1: Time series, 0: Panel data	0.54	0.49
ii. Method of analysis			
ARDL	Method for cointegration; 1:ARDL bounds test, 0: otherwise	0.88	0.28
PEDR	Method for cointegration;1: Pedroni, 0: otherwise	0.21	0.41
JOHA	Method for cointegration; 1: Johansen, 0: otherwise	0.05	0.22
TODA	Method for cointegration; 1: Toda-Yamamoto, 0: otherwise	0.07	0.25
COIN	Method for cointegration; 1: General analysis, 0: otherwise	0.52	0.49
iii. Countries in the study			
EURO	1: Europe, 0: otherwise	0.36	0.48
AMER	1: America, 0: otherwise	0.14	0.35
AFRI	1: Africa, 0: otherwise	0.12	0.33
ASIA	1: Asia, 0: otherwise	0.31	0.46
AUST	1: Australia, 0: otherwise	0.03	0.16
NCOU	Number of initial countries included in the analysis	18.04	9.66
NYEA	Number of years (time span) in each study	34.50	8.49
STYEA	Start year of the time span*	43.76	9.20
iv. Variables included in the long-run relationship			
ELEC	Electricity included in total energy consumption; 1: If electricity is included, 0: not included.	0.34	0.47
ECEL	Elasticity of GDP with respect to energy consumption.	0.54	0.39
PRDU	Prices of goods; 1: if P exists in the equation, 0: if it doesn't.	0.06	0.23
CAPI	Elasticity of capital.	0.27	0.20
CO_2D	CO_2 emissions; 1: if CO_2 exists in the equation, 0: if it doesn't.	0.01	0.10
LABD	1: if labor exists in the equation, 0: if it doesn't.	0.20	0.39
v. Causality			
BIDI	Bidirectional causality between EC and GDP; 1:yes, 0:no	0.22	0.41

* Year distance from present is reported, instead of the actual year.

Table 3
Meta-regression results of energy consumption and GDP growth.

	Meta regression model	
	Coefficient (St. error)	*p*
Constant	27.12 (169.17)	0.872
TIPA	108.50 (75.17)	0.150
ELEC	−187.38 (71.82)	0.009**
ARDL	260.12 (96.22)	0.007**
PEDR	261.14 (96.29)	0.007**
COIN	14.29 (69.48)	0.837
NCOU	5.06 (2.95)	0.088**
NYEA	−2.12 (5.59)	0.781
STYEA	−1.32 (5.65)	0.814
PRDU	−280.67 (83.44)	0.009**
CAPI	0.85 (0.13)	< 0.001*
CO_2D	−26.98 (98.95)	0.783
LABD	−43.32 (119.34)	0.716
BIDI	0.13 (0.05)	0.020*
STAB	122.44 (79.71)	0.125
Adjusted R^2	0.64	
F	33.70	
Observations	247	

* 5% significance
** 10% significance.

of dummy type, they will be interpreted in terms of their directional effect on the dependent variable. For instance, the level of prices is significant with a negative sign meaning that when it was added in the cointegration equation, those studies reported on average lower elasticities of GDP with respect to energy consumption. The same applies when electricity was included in the energy consumption. For studies where instead of the energy consumption variable, electricity consumption is used, there is tendency for a smaller GDP elasticity with respect to electricity (energy) to be reported. The elasticity of GDP with respect to energy consumption was also higher when bidirectional causality between energy consumption and growth was noted, namely when the feedback hypothesis was confirmed. Also, the number of countries in each study, appear to be a factor that positively affects the elasticity of GDP growth with respect to energy consumption at 10% level of significance. Single country studies have been blamed to produce biased results and spurious inference [17]. Our study provides evidence that the number of countries in the analysis also plays a role. When more countries are examined, their interdependence is taken into account.

As far as the utilized methods for the cointegration equation and causality framework are concerned, ARDL and Pedroni are significant at 10% with positive signs which means that studies employing these two methods yielded on average higher GDP elasticities. These two methods belong to the third and fourth generations of the econometric methods used in the investigation of the energy consumption and GDP growth nexus [22] and therefore the produced results are more robust.

It is understood that each cointegration method has some particular characteristics and enjoys some advantages over other cointegration methods. For example the ARDL method, as compared to Engle and Granger (COIN variable) and Johansen (JOHA variable) has the following privileges, according to [25]: (i) no need for all the variables in the system be of equal order of integration, (ii) it is an efficient estimator even if samples are small and some of the regressors are endogenous, (iii) it allows that the variables may have different optimal lags, and (iv) it employs a single reduced form equation. However, to cross-validate whether the ARDL cointegration equation does indeed yield higher GDP elasticities with respect to energy consumption is an object for further research. We need to be cautious with this finding, because not all methods are used for elasticities estimation and the sample is not balanced, hence some methods are overrepresented.

The geographic variables were not significant and hence were dropped from the model. It was our anticipation that developing

countries would exhibit a higher elasticity of GDP with respect to energy consumption, since these countries usually are characterized by high energy intensity. However, since developing and developed countries exist in all continents, geographical categorization might have yielded significant results at a country development level and not at a continent level. However, our continent separation could also serve to catch possible climatic effects if equal numbers of studies had taken place worldwide.

The data time span or their start date as well as the data type (time series or panel data) were not significant in affecting the size of the GDP elasticity with respect to energy consumption.

6. Conclusion

For less than half century, energy efficiency and environmental considerations have been placed in the forefront of policymaking agendas. By reducing energy consumption, so will greenhouse gas emissions and sustainable development will be enhanced. An ongoing debate is the extent to which a reduction in energy consumption, will also cause a reduction in income and GDP growth, which is not wished. Economies with different socio-political and economic characteristics will react differently to a reduction in energy consumption. Therefore, a vast number of studies have taken place in the so-called energy consumption and GDP growth nexus, following different econometric methods, with various data spans and data types and in various countries.

However, the problem with these studies is that they are not conclusive about policy recommendation across countries or to groups of countries. Of course the implementation of a policy is much more complicated that the results of the empirical research might suggest and there are always many more parameters to be considered such as infrastructure, political constraints and energy efficiency considerations which are only few of them.

This work has offered a meta-regression analysis of 51 published studies involved in the energy consumption-GDP growth nexus during the last two decades. It is the only meta-analysis in the field and facilitates a more rigorous overview of other studies which are pure narrative surveys. Because the results from individual studies are still inconclusive, a meta-regression perspective examines the overall strength of specified characteristics of the studies in the reported elasticity of GDP with respect to energy consumption.

Meta-regression results provide evidence that the elasticity of energy consumption is not independent of the econometric analysis type employed each time. Also, the former is affected by the inclusion of other variables in the equation for the long-run relationship between energy consumption and growth, such as the price level, number of countries participating in the data set, electricity as a component to the overall energy consumption or when bidirectional causality is present. This constitutes evidence that the omitted variable problem is a situation not to be ignored.

Additional research should take place in developing countries in order for the meta-sample to become more balanced and representative with respect to countries and perused methods in the future. More advanced econometric methods should be applied in the analyses. Also a wider number of variables must enrich the multivariate framework each time in order to reduce omitted variable bias.

The studies included in the analysis are not homogeneous since we have pooled together binary and multivariate models. Due to the heterogeneity of studies, our results might be biased to some degree. Pooling heterogeneous studies together is as if adding apples together with oranges. Therefore, enriching the dataset in ten years time or compiling it from scratch with the attention focused on other variables is worthy of trying in the future when more studies in the field will have become available.

Acknowledgment

The authors would like to thank two anonymous referees for their instructive comments in the improvement of this paper. The usual disclaimer applies.

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